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No. 445

TENSILE STRENGTH OF WELDED STEEL TUBES

First Series of Experiments

By A. Rechtlich

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TENSILE STRENGTH OF WELDED STEEL TUBES.*

First Series of Experiments.

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Contents

I. Purpose of Experiments

The purpose of the experiments was to determi[n] ence in the strength of steel tubes welded by diff[e] as compared with one another and also with unwelde[d] tubes, including, moreover, a comparison of the re[

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by experienced and inexperienced welders.

In a further series of experiments, it is intended to compare the strength of welded steel-tube joints with the strength of unwelded annealed tubes.

II. Experimental Tubes

The experimental tubes were prepared from ordinary commercial steel tubing and were not annealed after welding. With the exception of sulphur, which should not exceed 0.03%, the chemical composition of these tubes was normal, as given below, and they welded well.

Carbon	0.120%
Silicon	0.012%
Manganese	0.360%
Phosphorus	0.036%
Sulphur	0.061%

Fig. 1 shows the various types of joints. Types A-G consisted of two tubes of 27 mm (1.06 in.) diameter and 1 mm (0.04 in.) thickness of wall. Types H-M were combinations of tubes 27 × 1 mm (1.06 × 0.04 in.) with tubes 30 × 1.5 mm (1.18 × 0.06 in.). The total length of the experimental tubes was 25 cm (9.84 in.). The cross section of the 27 × 1 tube was 81.6 mm^2 (0.126 sq.in.).

Tubes A were plain unwelded tubes. Tubes B were butt-welded, as also tubes C, D, E, and G, on each of which two reinforcing strips or "laps" were welded, as shown in Fig. 1. Tube F was reinforced by a strip or lap on the inside.

In the tables, the index letters of the tubes are accompanied by the small letters a, b, and c, to indicate the thickness, 1 mm, 1.5 mm, or 2 mm (0.04, 0.06, or 0.08 in.) of the respective reinforcing laps. Three of each type of joint were welded by an experienced workman and two by an inexperienced workman (excepting type H, which was welded four times by an experienced welder). Fig. 2 shows a few ruptured tubes which had been joined by an experienced welder, and Fig. 3 shows similar ones, which had been joined by an inexperienced welder. The welds have a more uniform appearance in Fig. 2 than in Fig. 3.

III. Weld Wire

Ordinary weld wire of 1 mm (0.04 in.) diameter was used for welding. The wire flowed well and emitted very few sparks. Its chemical composition included

Carbon	0.100%
Silicon	0.070%
Manganese	0.320%
Phosphorus	0.010%
Sulphur	0.044%

The percentages of silicon and sulphur were rather high. Normally, silicon should not exceed 0.03% and sulphur should not exceed 0.02%.

IV. Laps

The reinforcing laps consisted of strips of polished sheet iron of 37-44 kg/cm² (526.3-625.8 lb./sq.in.) tensile strength and 20-25% elongation. This sheet iron welded finely. No chemical analysis was made of it.

V. Preparations for the Tests

A. Preparation of the experimental tubes.- These were welded by laying the halves in an angle iron (Fig. 4), in order to bring the ends accurately together. This purpose was accomplished for telescoping tubes by making them fit tightly.

In welding on the laps, the welding was begun at the tips of each lap and continued toward the joint. Thus, less of the tube was annealed. In Fig. 1 the direction of welding is indicated by small arrows.

B. Mounting the experimental tubes.- This occasioned difficulties at first, since no special holding devices were available. Attempts in which the tube ends were squeezed flat and provided with insets and held in ordinary vices, often resulted in the rupture of the tubes at the point of transition from the round to the flattened portion. This always occurred in determining the breaking strength of unwelded tubes. Moreover, the tube was drawn flat, i.e., its cross section became elliptical. It was only after the adoption of the device shown in Fig. 5 that the tubes retained their roundness during the tests. This mounting consists of

1. Schenck's 15-ton universal machine for testing tensile strengths;
2. Slide;
3. Spherical inset;
4. Collar with conical opening;
5. Conical plug.

The two latter pieces have a conical taper of 1 : 25. Both are hardened and can be used only for tubes 27 × 1 mm (1.06 × 0.04 in.).

Preliminary tests with this mounting showed the necessity of providing the ends of the experimental tubes with a sawed slit. The length of this slit was about 3/4 the height of the conical collar. Whem the slit was about equal to the height of the conical collar, the tube was ruptured at the clamping point. In Fig. 2, one of the slits can be seen in the horizontal tube A. The experimental tubes A-G were all mounted as shown in Fig. 5.

The mounting and unmounting were very troublesome and tedious. In mounting, the conical collar was first forced over one end of the tube and the plug was driven in lightly. Then the spherical inset, the slide and the second conical collar were forced on. Lastly, the second plug was driven in. This had to be done while the conical collar was not on the end of the tube, because otherwise, it would have been impossible to drive it in properly. The introduction of the second plug was difficult, because all the other pieces had to be on the tube first. Fig. 6 shows an experimental tube before mounting in the testing machine.

After the rupture, the removal of the conical collar and plug was often difficult, because they were on very tight. The tube had to be sawed in two between the weld and the collar, as the best way to remove the latter. The sawing took less time than to compress the end of the tube which had been expanded by the conical plug.

Tubes H-M were attached by the above device only at the smaller end. The larger end was brought to a red heat and flattened. After the insertion of a simple filling piece, this was held in the socket of the testing machine by ordinary clamp plates, as shown in Fig. 7. The flattening of the larger tube was perfectly safe, since the break would naturally occur in the smaller tube. The larger end could therefore be removed without sawing.

The actual breaking test lasted 1-2 minutes, though the whole operation of fastening and removing the tubes required 8-10 minutes. The above-described methods of attaching proved very satisfactory in all the experiments. In only one instance did the tube (D_{b_2}) fail at the point of attachment.

VI. Execution of the Tests

After mounting the tube in the testing machine, a preliminary tension of 1500-2000 kg (3307-4409 lb.) was first applied by hand, in order to see whether the tube was securely mounted. Then the electric drive was switched on and the force was increased until rupture occurred.

At a load of about 2500 kg (5500 lb.) scales fell off abundantly near the weld, due to the greater stretching of the annealed portion. At about 3000 kg (6600 lb.), the tube began to contract on each side of the weld at the end of the annealed zone until rupture occurred, which was within 10-20 mm (0.4-0.8 in.) of the weld.

VII. Test Results and Their Evaluation

The accompanying table contains the numerical results of the tests, which are represented graphically in Fig. 9, as a summary of the whole series of tests.

Butt-Welded Tubes

Tubes A.- The breaking strength of an unwelded tube was first determined as a criterion or basis of comparisom for the strength of the welded tubes. The mean of three tests was 52.6 kg/mm^2 (74,800 lb./sq.in.), which was adopted as 100% for purposes of comparison. The results of these tests varied very little, the difference between the maximum and minimum being only 2.4%

In two cases the break was zigzag. In one case it was at an angle of about 45° to the axis of the tube. It lay at about a third of the tube length, near the point of attachment. After passing the elasticity limit, there showed plainly, on the previously smooth surface, lines which were inclined about 45° to the axis of the tube (Fig. 8).

Tubes B.- The simple butt weld of two tubes of like diameter by an experienced welder showed a mean breaking strength of 92.5%. The breaking strengths differed very little from one another, the minimum value being 92.3% and the maximum 92.8%, which demonstrated the reliability of a well-made butt weld.

An inexperienced welder obtained a mean breaking strength of 78.8%. In one case the break occurred in the weld seam, though even in this case, the breaking strength was hardly any less.

The difference between the products of the experienced and inexperienced welder was quite large (14%). The smallest breaking load in the former case was 3960 kg (8730 lb.) and in the latter case, 3385 kg (7463 lb.) (See table). An inexperienced welder works slower and less uniformly and thus damages the material more with the welding flame. His work is therefore more expensive, as well as poorer.

In both cases the breaks occurred at the end of the annealed zone. Some of these ruptured tubes are shown in Figs. 2 and 3 under B, B'_1, and B'_2. Tube B (experienced welder) shows a regular break parallel to the weld seam. The contraction is clearly evident, beginning with the annealed zone. The tubes B'_1 and B'_2 (inexperienced welder) exhibit irregular breaks. In B'_1 it can be seen that a portion of the break follows the weld seam.

Tubes C.- The welding on of tapering laps did not greatly increase the strength of the butt welds made by experienced welders, the breaking strength being 92.8, 91.2, and 91% of the criterion. The joints made by inexperienced welders were considerably improved by the welded-on laps, the mean strength increasing to 85.1%. The strength increase of 78.5% in comparison with the butt-welded joint is considerable (See table).

Table of Test Results

Tube	Breaking load kg	Breaking strength kg/mm²	Mean breaking strength kg/mm²	Breaking strength in %	Nature or location of break
			Unwelded tube.		
A_1	4350	53.2			Zigzag break.
A_2	4250	52.1	52.6	100	Under 45°.
A_3	4300	52.6			Zigzag break.
			Butt-welded tube.		
B_1	3960	48.5			
B_2	3960	48.5	48.6	92.5	In annealed zone.
B_3	3975	48.7			
B'_1	3335	41.4	41.45	78.8	1/3 in weld seam.
B'_2	3390	41.5			In annealed zone.

Table of Test Results (Cont.)

Tube	Breaking load kg	Breaking strength kg/mm²	Mean breaking strength kg/mm²	Breaking strength in %	Nature or location of break
Butt-welded tube with long tapering laps, 1 mm (0.04 in.) thick.					
C_{a_1}	4020	49.3	48.1	92.8	In annealed zone.
C_{a_2}	3900	47.8			
C_{a_3}	4000	49.0			
$C_{a'_1}$	3660	44.8	44.7	85.1	
$C_{a'_2}$	3650	44.7			
Butt-welded tube with long tapering laps, 1.5 mm (0.06 in.) thick.					
C_{b_1}	3745	45.8	47.8	91.0	In annealed zone.
C_{b_2}	3900	47.8			
C_{b_3}	4055	49.7			
Butt-welded tube with long tapering laps, 2 mm (0.08 in.) thick.					
C_{c_1}	3970	48.7	47.9	91.2	In annealed zone.
C_{c_2}	3840	47.0			
C_{c_3}	3940	48.2			
$C_{c'_1}$	3570	43.7	43.15	82.0	
$C_{c'_2}$	3485	42.6			
Butt-welded tube with short tapering laps, 1 mm (0.04 in.) thick.					
D_{a_1}	3915	48.0	47.7	90.8	In annealed zone.
D_{a_2}	3800	46.6			
D_{a_3}	3785	46.4			
$D_{a'_1}$	3190	39.1	39.3	74.7	
$D_{a'_2}$	3220	39.5			
Butt-welded tube with short tapering laps, 1.5 mm (0.06 in.) thick.					
D_{b_1}	3795	46.5	46.3	88.0	In annealed zone.
D_{b_2}	3725	46.0			At attachment. Not valid.
D_{b_3}	3770	46.2			In annealed zone.

Table of Test Results (Cont.)

Tube	Breaking load kg	Breaking strength kg/mm²	Mean breaking strength kg/mm²	Breaking strength in %	Nature or location of break
Butt-welded tube with short tapering laps, 2 mm (0.08 in.) thick.					
D_{c1}	3945	48.3			
D_{c2}	3955	48.5	48.4	92.0	In annealed zone parallel to weld seam.
D_{c3}	3930	48.2			
$D_{c'1}$	3290	40.3	40.45	76.9	
$D_{c'2}$	3310	40.6			
Butt-welded tube with circular laps, 1.5 mm (0.06 in.) thick.					
E_{b1}	3860	47.2			
E_{b2}	3830	46.9	46.7	88.8	In annealed zone parallel to weld seam.
E_{b3}	3750	46.0			
$E_{b'1}$	3315	40.6	40.5	77.0	
$E_{b'2}$	3300	40.4			
Butt-welded tube with circular laps, 2 mm (0.08 in.) thick.					
E_{c1}	3930	48.2			
E_{c2}	3975	48.6	48.4	92.0	In annealed zone parallel to weld seam.
E_{c3}	3975	48.6			
$E_{c'1}$	3370	41.3	40.7	77.5	
$E_{c'2}$	3270	40.1			
		Butt-welded tube with inserted lap			
F_1	3900	47.8			In annealed zone parallel to weld seam.
F_2	3885	47.6	47.5	90.4	
F_3	3750	47.2			
F_1''	3350	41.1	41.0	78.0	At corner of attachment.
F_2''	3340	40.9			In annealed zone.
Butt-welded tube with rectangular laps, 1.5 mm (0.06 in.) thick.					
G_{b1}	3875	47.5			
G_{b2}	4005	49.1	48.7	92.7	
G_{b3}	3965	48.6			In annealed zone.
$G_{b'1}$	3360	41.2	41.25	78.5	
$G_{b'2}$	3370	41.3			

Table of Test Results (Cont.)

Tube	Breaking load kg	Breaking strength kg/mm²	Mean breaking strength kg/mm²	Breaking strength in %	Nature or location of break
Butt-welded tube with rectangular laps, 2 mm (0.08 in.) thick.					
G_{c1}	3845	47.1	47.2	89.1	In annealed zone.
G_{c2}	3900	47.8			
G_{c3}	3825	46.8			
$G_{c'1}$	3650	44.7	44.6	84.9	
$G_{c'2}$	3630	44.5			
Telescoped tubes with transverse weld.					
H_1	3400	41.6	41.25	78.5	In annealed zone parallel to weld seam.
H_2	3300	40.4			
H_3	3420	41.8			
H_4	3360	41.2			
H'_2	3380	41.4	41.25	78.5	
H'_1	3350	41.1			
Telescoped tubes with oblique weld.					
J_1	4190	51.4	45.2	86.0	In annealed zone parallel to weld seam.
J_2	3450	42.3			
J_3	3430	42.0			
J'_1	3420	41.8	42.35	80.5	
J'_2	3500	42.9			
Telescoped tubes with two overlapping points.					
K_1	4210	51.5	48.5	92.2	In annealed zone parallel to weld seam.
K_2	4150	50.8			
K_3	3500	42.9			
K'_1	3470	42.5	43.75	83.2	
K'_2	3670	45.0			
Telescoped tubes with slot welds					
L_1	3225	39.5	43.4	84.5	In annealed zone parallel to weld seam.
L_2	3220	39.4			
L_3	4175	51.2			
L'_1	3270	40.1	35.75	67.8	One seam did not hold.
L'_2	2550	31.3			

Table of Test Results (Cont.)

Tube	Breaking load kg	Breaking strength kg/mm²	Mean breaking strength kg/mm²	Breaking strength in %	Nature or location of break
		Telescoped tubes with hole welds			
M_1	3000	36.8	38.2	72.6	1 weld point sheared off.
M_2	3100	38.0			4 weld points torn out.
M_3	3260	40.0			3 weld points sheared off. 3 weld points torn out.
M_1'	2850	34.9	34.9	66.4	All 6 weld points sheared off.
M_2'	2850	34.9			3 weld points sheared off. 3 weld points torn off.

On the other hand, the thickness of the welded-on laps had very little effect on the strength of the joints. The best results were obtained with 1 mm (0.04 in.) laps, which are also preferable on account of their smaller weight.

It is easier, however, to weld the thicker laps, because the thin laps melt readily. This happens especially with inexperienced welders. In Fig. 3, it is easily seen how, for this reason, in tubes C_a' and D_a', the seam is more irregular than in tube C_a' with thicker laps. With skillful welding, all the seams look well. With unskillful welding, the strength of the experimental tubes decreased a little with increasing thickness of the laps, probably because the tubes were annealed more by exposure to the flame during the somewhat longer period required to fuse the laps.

Tubes D.- The laps were tapered less. The experienced welder obtained somewhat lower strengths than by butt welding (See table). This may be due, in part, to the fact that the same tube, which had already been annealed in the butt-welding, was again exposed to the flame, which may have further weakened the material. This also occurred, to some extent, in the preceding case, but was greater in the latter case, because the laps were shorter than the already annealed portion of the tube. On these tubes the annealed portion was about the same as on the simple butt-welded ones. With an inexperienced welder the loss in strength was still greater, its mean values being 74.7 and 76.9%, while that of the simple butt-welded tube was 78.8%.

In the above case, there was therefore a loss in strength combined with increased weight, which was just the opposite of what was desired. It follows therefore that it is useless to weld laps on a butt-welded joint, if the laps are shorter than the annealed portion of the tube.

Tubes E.- With an experienced welder, no increase in strength was obtained, in comparison with simple butt-welding, by the use of circular laps (Fig. 9). The slight differences in strength between the tubes with 1.5 and 2 mm laps, and in comparison with the tubes D, lie well within the usual deviations. This also holds good for the welds made by inexperienced welders.

In general, the conclusion may be drawn from the results with tubes C, D, and E, that the more pointed the laps are in the direction of the axis of the tube, the more the strength is increased. Thereby the lap welds are longitudinal, so that, next to the annealed portion of the tube there is also an unannealed portion, and a larger surface of rupture is obtained (Fig. 11). The best shape for the laps must, however, be determined by later experiments in relation to the tube diameter.

Tubes F.- Here also the strength values of 90.4% for the experienced and 78% for the inexperienced welder fell below those of the simple butt-welded tubes. The operation was more difficult, however, because the thinner walls next to the inserted piece melted very easily. Inserted laps are therefore less advisable than outside laps.

Tubes G.- Rectangular laps gave almost the same results as tubes C with the pointed laps. (See table). The strength was between the simple butt-welded tubes and the tubes C. Here also it was demonstrated that longitudinal seams are preferable to lateral seams. With the tube Gc', even the inexperienced welder obtained a strength of 84.9%, as compared with 78.8% (mean values) for butt-welded tubes.

B. Telescoped Tubes

Tubes H-M were welded unions of telescoped tubes. This type of joint occurs oftenest, for example, in fuselage construction.

Tubes H.- The tubes were joined by lateral welding. It is noteworthy that this type of joint was much weaker than that resulting from the butt-welding of tubes of like diameter (Tubes B, 27 × 1 mm = 1.06 × 0.04 in.). By this method an experienced welder obtained only 78.5% of the strength of an unwelded tube, as compared with 92.5% for simple butt-welded tubes B, the former value being even below the 78.8% obtained by an inexperienced welder with tubes B'.

Here also it is noteworthy that the breaking strengths obtained by experienced and inexperienced welders were about the same with very little scattering. The results of the six tests did not differ over 3.5% from one another.

The great difference in the strength of this type of joint, in comparison with butt-welded joints, was therefore probably due to the fact that, in butt-welding, the tube ends fused quicker and the joint was made quicker, with less annealing of the tubes than in the welding of telescoped tubes.

Tubes J.- These were welded at an angle of 45°. The resulting strength was considerably greater than that of the lateral or crosswise welds (See table). The minimum values obtained both by inexperienced and by experienced welders were higher than the maximum values obtained by lateral welding. The mean value obtained by the experienced welder was 86% of the criterion, the maximum value being 97.7% and the minimum value being 79.8%. Correspondingly the inexperienced welder obtained a mean value of 80.5%, a maximum of 81.5% and a minimum of 79.5%.

The break was parallel to the seam (Fig. 2). The strength was increased by increasing the surface of the break, since the annealed zone did not then cover a complete cross section, but there was always an unweakened portion alongside an annealed weakened portion. Even a flaw in the weld seam did not have so much effect on the strength of the joint, as in the case of a lateral weld. In making the weld, the flame was pointed in the direction of the larger tube. The weld direction is indicated by the arrows in Fig. 1.

Tubes K.- The maximum strength of welded telescoping tubes was obtained with outer tubes having doubly tapered ends, the results being almost the same as for tubes B and C. A mean strength of 92.2% of the criterion was obtained by the experienced welder, the maximum being 98% and the minimum 81.6%. By this method the inexperienced welder also obtained his highest values: a mean of 83.3%, maximum 85.6%, minimum 80.8%, these values being higher than the corresponding values for butt-welding by an inexperienced welder.

The strength increase is ascribable to the same reason as for the J type of joint. With the tubes K the manner of welding was very simple. Care had to be taken, however, always to begin the welding at the tips and direct the flame toward the larger tube, as shown by the arrows in Fig. 1. The shape of the break is shown by Fig. 2. It was parallel to the seam at the end of the annealed zone.

Tubes L.- The joining of telescoped tubes by welding through slots lengthwise of the tubes produced especially fluctuating results. This method of welding was more difficult than either of the three previously described methods.

The difficulty resided in the fact that the free edges of the slots of the outer tube very easily melted and flowed away. One was liable to be led by this fact to apply the weld wire too soon, before the inner tube fused sufficiently. Consequently, the weld was only superficial and did not hold. In the event of a successful weld, a very high strength was attainable, as was demonstrated by the maximum strength of 97.4% obtained by an experienced welder. His minimum result was 81.6% and his mean result was 84.5%. With the inexperienced welder, the abovementioned case occurred, of a weld that was only superficial, so that the minimum strength was only 59.5% of the criterion, the mean value being 67.8%, and the maximum 76.1%. Fig. 10 shows the successful union under L_1', and the unsuccessful one under L_2'.

One great disadvantage of this method resides in the fact that moisture can get inside the tube, this being particularly liable to happen when the inner tube is contracted by high stresses at the unwelded points. This phenomenon is apparent in Fig. 10.

Tubes M.- Less fluctuating but nevertheless the lowest strengths resulted from the welding of two telescoping tubes through holes in the outer tube. The experienced welder obtained a mean value of 72.6% of the criterion, the minimum being 70% and the maximum 76.1%. The inexperienced welder obtained a mean of 66.4%. The maximum strengths obtained by this method were, in fact, below the minimum results of lateral or cross welding.

The low strength was doubtless due to the fact that the welded points were not large enough; perhaps also because 6 was an inadequate number of welding points. In some instances the welds were sheared off and in others torn out. These points can be seen in Fig. 3. It can safely be assumed that the strength can be increased by making the weld points somewhat larger, so that shearing cannot occur. This method, however, also has the disadvantage that moisture can get inside the tubes.

VIII. Recapitulation

In conclusion it can be said that a well-executed butt-weld is very strong. The safety of such a weld against defect is considerably increased, however, by welding two tapering laps, of about the thickness of the walls of the tubes, on opposite sides of the joint. These laps should extend longitudinally beyond the region annealed by the butt-welding (Tubes C), so that, alongside the annealed portions of the tube, there will also be unannealed portions (Fig. 11). In each case, however, it must be considered whether the increase in strength from the added strips is sufficient to justify the accompanying increase in weight.

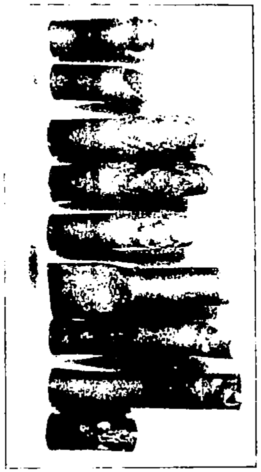
Inserted strips are more difficult to weld, because the adjacent walls of the tubes easily melt away. In the tests they did not produce breaking strengths greater than those of simple butt welds.

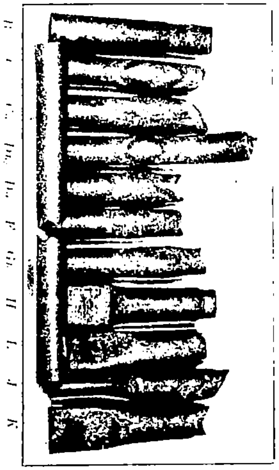
In the welds of telescoping tubes, the oblique and doubly tapered tips of the outer tube produced better joints than simple lateral welding.

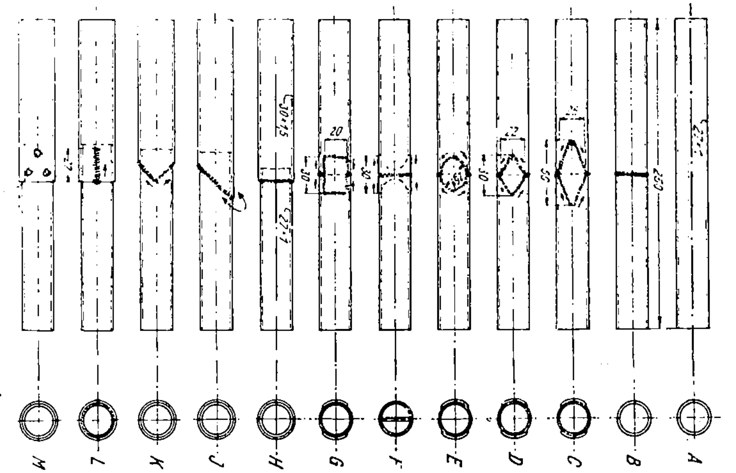
Slot-welding can give very high strength values, but great care must be exercised to obtain a good weld.

The same statement applies to hole-welding. In the last two cases moisture can get inside the tubes, thereby greatly impairing the advantages of the attainable high strengths.

Translation by Dwight M. Miner,
National Advisory Committee
for Aeronautics.



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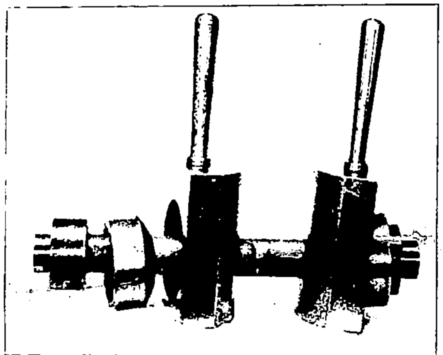

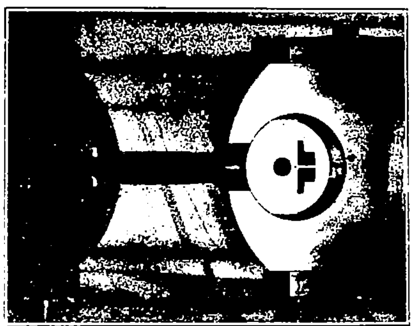

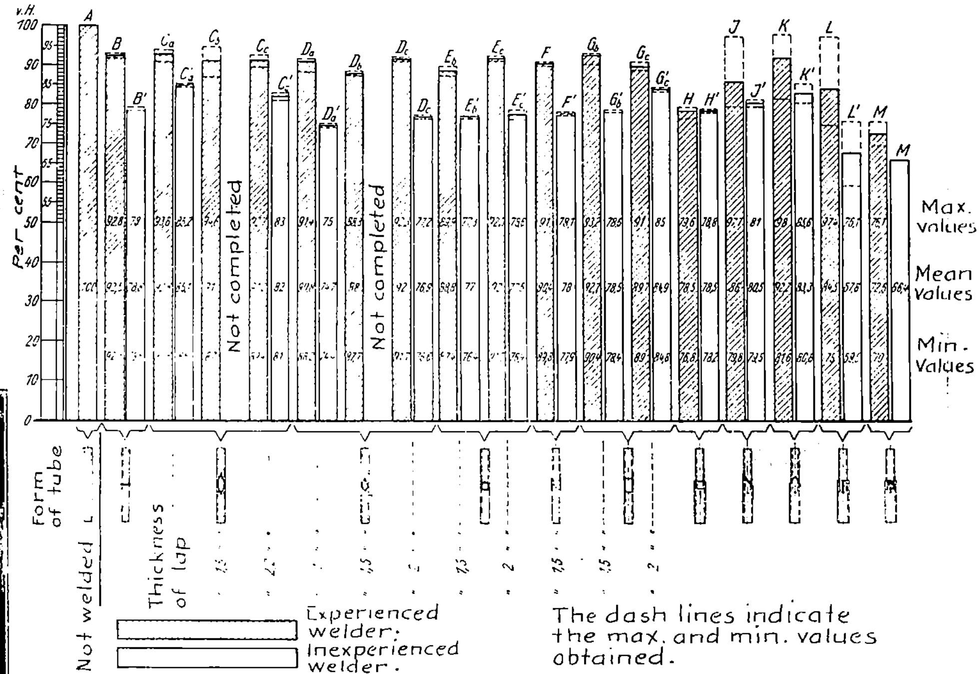
v.H.
Per cent
Not completed
Not completed
Max. values
Mean values
Min. values
Form of tube
Not welded
Thickness of lap
Experienced welder;
Inexperienced welder.
The dash lines indicate the max. and min. values obtained.

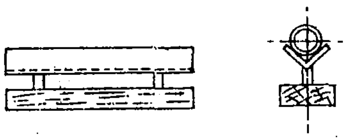

Fig.4 Device for welding tubes of like diameter.

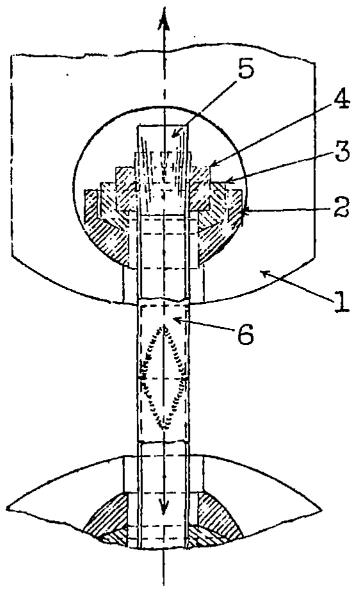

Fig.5 Mounting for tensile test.

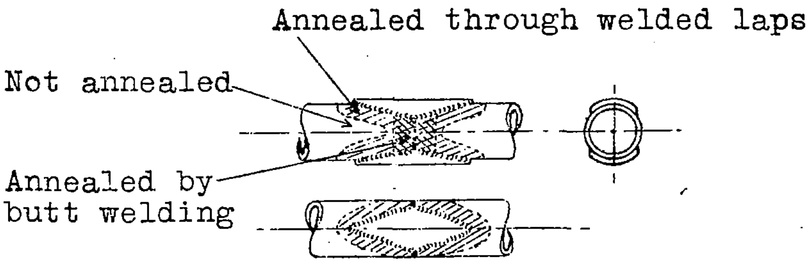

Fig.11 Annealed zone of a weld.